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HYDROCARBONS IN HOUSTON AIR

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ABSTRACT

Ambient air samples were collected in Houston downtown and industrial areas to determine hydrocarbon composition and concentrations. Twenty-one sampler were collected on three days of sampling: September 1, 1973, and January 30 and April 2, 1974. The results of the detailed hydrocarbon analyses of these samples are presented and suggest that both vehicular and industrial sources of hydrocarbons are important. Some of these samples were collected during periods of extremely stagnated meteorological conditions. It was observed that although the total nonmethane hydrocarbons were high, they did not exceed 10 ppmC. Measurements of nitrogen oxides were made for some of these samples. These samples suggested that the NMHC/NO_x ratio in the Houston area was not atypical, usually ranging from 10/1 to 20/1.

This report covers a period from September 1973 to April 1974 and work was completed as of June 1977.

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SECTION I

INTRODUCTION

Early in 1973 a task force consisting of several scientists from the State of Texas Air Control Board (TACB) visited the U.S. Environmental Protection Agency (EPA at Research Triangle Park, North Carolina) to discuss the hydrocarbon (HC) and oxidant problems of the Houston area. In general, their concern was the proposed use of transportation control strategy to control HC emissions and ultimately photochemical ozone (O_3). It was the TACB contention that this strategy would be ineffective for the Houston area since industrial sources of hydrocarbons were more abundant than automotive sources. Total non-methane hydrocarbons (NMHC) exceeding 10 ppmC were expected at many ground level sites throughout the industrial area. It was suggested that the Houston atmosphere was atypical in that HC/NO_x ratios there were much higher than in other cities and that these high ratios would result in higher urban O_3 concentrations in Houston. It was also conjectured that due to the high paraffin nature of the ambient HC mix, O_3 lifetimes may be longer. The data base to support these contentions was at that time sparse and unreliable (1).

The EPA Environmental Sciences Research Laboratory (ESRL; at that time, Chemistry and Physics Laboratory) was funding a contract with Washington State University (WSU) for the measurement of HC composition and concentration, along with corresponding O_3 concentration, at five urban sites. Houston was selected as one of the urban sites, and a study was commenced during the month of October 1973. An interim report on the WSU study is available (2).

Prior to and on two occasions after the WSU study, grab samples of Houston ambient air were collected in Tedlar bags and analyzed by the ESRL Mobile Laboratory. Twenty-one samples were collected on the three sampling days: September 11, 1973, January 30, 1974, and April 2, 1974. This report

describes the results of these grab samples studies.

Also included in this report is a meteorological analysis of Houston and the surrounding area on collection days, since meteorological conditions affect both photochemical and dispersion characteristics of ambient air. It would be virtually impossible to relate observed O_3 concentrations to the NMHC found in this short, three-day sample collection program. Consequently, the meteorological evaluation was limited to: (1) the dispersion characteristics of the ambient air and (2) the relationship of mixing characteristics to observed HC concentration levels.

Since these initial air sampling programs, two additional studies were performed in the Houston area that are pertinent to the discussion in this report. The first study consisted of a detailed one-month field sampling program funded by EPA and conducted by WSU in July 1976 (3). The second study was a report by Whitehead and Sievers (4), again in 1976, of high NMHC measurements, average 8.7 ppm, observed in Jones State Forest 40 miles north of Houston. The latter authors reported that natural HC sources in the Houston area may be sufficient to produce O_3 concentrations which exceed the Federal 80 ppb O_3 standard. In response to this report, Seila (5) undertook a bag sampling program on January 4-6, 1978, at sites similar to those used by Whitehead and Sievers. Seila's results suggest HC levels at least 20 times lower than those reported by Whitehead and Sievers. The HC composition for the most part resembled that of diluted urban air. Natural HC in these samples consisted predominately of alpha-pinene at concentrations less than 10 ppbC.

SECTION 2

CONCLUSIONS

These studies demonstrated that the high NMHC levels (>10 ppmC) suggested for the Houston industrial areas were not observed. Also, industrial HC emissions do not necessarily dominate the total NMHC, and a considerable portion of these hydrocarbons are of vehicular origin. Finally, the HC/NO_x levels, although high, are not atypical when compared to other urban areas.

The results of a 3-day study cannot be termed as conclusive; however, these results are in general agreement with the WSU measurements (2,3).

SECTION 3

RECOMMENDATIONS

This study represented an initial effort by EPA to measure HC composition and concentrations in the general Houston area. Since 1973 and 1974, additional studies have been conducted in the Houston area to assess the air quality for several pollutants including the hydrocarbons. Future EPA programs will commence in the Houston area to test air quality simulation models. An intricate part of this study will be an area-wide NMHC assessment.

The general area of Houston represents a wide diversity of industrial and vehicular sources. Both accountable and fugitive HC emissions are expected to be enormous. In order to invoke viable HC control strategy, a reliable emission inventory of all these sources is needed. Ambient air samples for hydrocarbons representing combined emissions from these sources will provide valid emission inventories. Therefore, studies of detailed NMHC composition and concentration are important and should continue.

SECTION 4

EXPERIMENTAL PROCEDURES

The gas chromatography procedure and cryogenic concentration system for the analysis of grab samples in 1973 and 1974 are reported elsewhere (6,7). Twenty-liter, two-mil, Tedlar P.V.F. (DuPont, Wilmington, Delaware) bags were filled to half-capacity with a metal bellows pump (Metal Bellows, Sharon, Massachusetts). The sample collection period ranged from 5 to 10 minutes. The sampling time and general collection site for each sample are given in Table I. The bags were shipped via air freight to the ESRL Mobile Laboratory for detailed HC analysis. The sample bags were partially inflated to preserve them during air freight shipment; however, some bags were lost in the aircraft baggage compartments that were not adequately pressurized.

If the sample bags were received within 24 hours of collection, as in the case of the September 11, 1973, study, NO and NO_x measurements were made with a Bendix Model 8101 NO_x chemiluminescent analyzer. The NO and NO_2 compositions were expected to change with time due to thermal oxidation of NO to NO_2. The NO_x value ($NO + NO_2$), however, even after a 24-hour storage period, should be representative of on-site ambient NO_x levels. The bag samples collected on January 30 and April 2, 1974, were stored for 48 to 190 hours before analysis; therefore, the NO_x analysis was considered unrepresentative due to NO_2 removal by the bag surfaces.

SECTION 5

RESULTS AND DISCUSSION

Sampling sites for each bag sample collected for the three studies are shown in Figure 1. A more detailed description of sample site and sample time are given in Table 1. As shown in the figure the vicinity chosen for most sampling was the ship channel area of Houston, since this is the general location of the industrial complex. It is from this area of Houston that maximum industrial HC emissions were expected. Since the three sampling days are separated by months and are characterized by different meteorological conditions, each day's results will be discussed independently.

September 11, 1973

The September 11 sampling initiated the effort to obtain information concerning HC pollutant composition of the Houston atmosphere. These samples were collected prior to the first WSU study (2). The results of the detailed HC analyses for the bag samples are given in Table A-1. In this study nine grab samples were collected. Samples HO3, HO4, HO6, HO7, and HO8 were collected in the vicinity of industrial activity to determine HC composition and concentration due to these industrial sources. Sample HO9 was collected on the eastern Texas gulf coast to estimate background HC composition and concentration coming across the gulf. Sample HO1 was collected somewhat north of downtown Houston but should be typical of the urban HC composition. Samples HO2 and HO5 were collected in the Washburn and Baytown tunnels to determine vehicular HC composition. Using acetylene (C_2H_2) as a normalizing compound and assuming that automotive sources are entirely responsible for ambient, C_2H_2, ratios of individual HC and HC sums were determined for these tunnel samples. These ratios were used to estimate the percentage of vehicular emissions in the other samples. Since non-automotive C_2H_2 sources have been identified for the Houston industrial areas, carbon monoxide (CO) measurements were also used to determine vehicular factors. Results for the sum (Σ)

TABLE 1. HOUSTON SAMPLING SITES

Code	Sampling time (C.D.T.)	Location
H01	1550	Reagan Road at Euclid Road
H02	1445	Baytown Tunnel
H03	1217	Pasadena (TACB site)
H04	1130	Jacinto City (TACB site)
H05	1155	Washburn Tunnel
H06	1310	Industrial Drive
H07	1340	Channel View
H08	1400	Decker Road
H09	1455	Red Bluff
H12	0650	Minden and Dabney Streets
H13	0720	Jacinto City (TACB site)
H14	0805	Pasadena (TACB site)
H15	0845	Queens Road & Revere
H16	1020	Jacinto City (TACB site)
H17	1115	Pasadena site (TACB site)
H18	1205	Downtown Houston
H21	0730	Jacinto City
H22	0800	Industrial Drive
H23	0815	Jacinto Port Road
H24	0920	Deer Park
H25	0940	Pasadena

of paraffins (P), olefins (O), and aromatics (A) ratios to both C_2H_2 and CO are given in Table 2. Although our two tunnel samples are insufficient to calculate a vehicular emission factor, McMurry et al. (9) in a 1975 Houston study, determined a vehicular emission factor of 8.09 $\pm$ .43 for the C_2-C_5 HC. This value compares well with our C_2-C_5 HC factor of 8.32 $\pm$ 0.62, determined for tunnel samples H02 and H05.

As shown in Table 2, the use of either CO or C_2H_2 as vehicular emission factors gave similar results of vehicular composition for samples H01, H03, and H04. For example, both CO and C_2H_2 factors indicate the vehicular fraction of sample H01 is approximately 40%. However, this is not the case for samples H06, H07, H08, and H09. In these samples the factor ascribes a considerably larger NMHC percentage to vehicular sources than does the C_2H_2 factor. This factor disparity is probably traceable to background CO

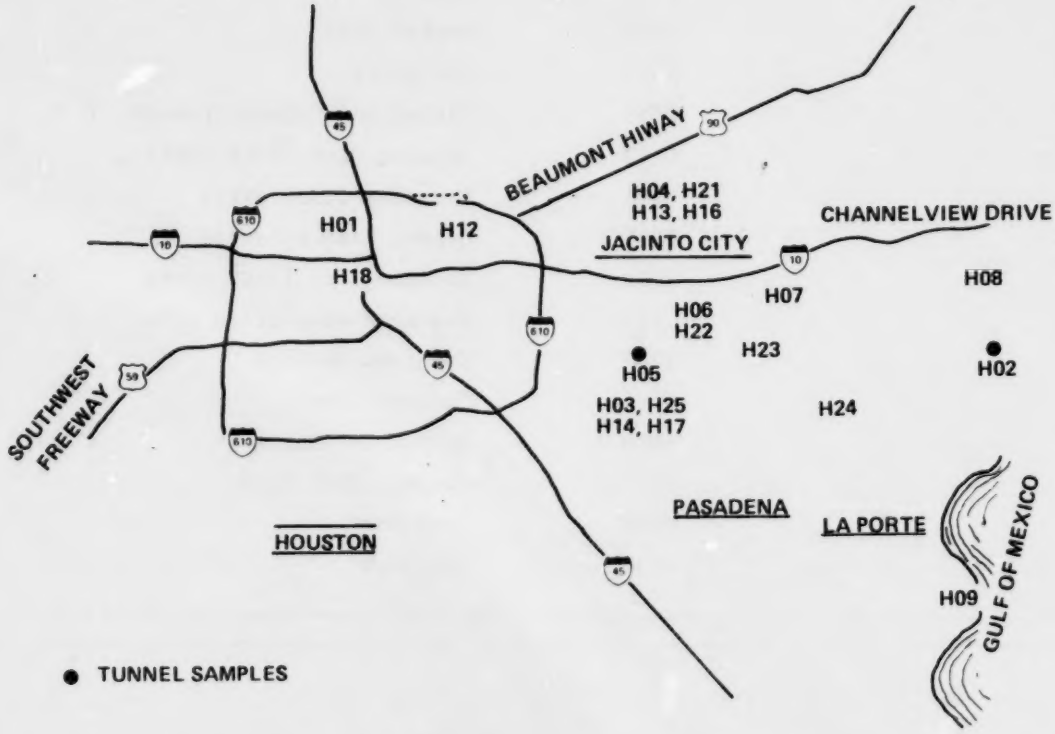

Figure 1. Geographic location of the grab sample collection sites.

TABLE 2. SEPTEMBER 11, 1973, MEASUREMENTS

Component	SAMPLE HO1	HO2	HO3	HO4	HO5	HO6	HO7	HO8	HO9
ΣP*	691.5	5101.4	244.7	205.0	6492.1	184.2	355.3	321.3	89.3
ΣO*	269.5	2164.4	71.6	61.4	2985.5	42.8	28.4	67.7	15.8
ΣA*	569.8	2552.3	135.5	102.2	3006.6	119.0	93.6	141.2	92.5
$\Sigma P/C_2H_2$	17.4	9.9	27.8	9.9	7.8	42.8	177.6	84.6	52.5
$\Sigma O/C_2H_2$	6.4	4.2	8.1	3.0	3.6	10.0	14.2	17.8	9.3
$\Sigma A/C_2H_2$	13.6	5.0	15.4	4.9	3.6	27.7	46.8	37.2	54.5
ΣP/CO	0.36	0.15	0.38	0.19	0.14	0.53	1.62	0.95	0.41
ΣO/CO	0.13	0.16	0.11	0.06	0.06	0.12	0.13	0.20	0.07
ΣA/CO	0.28	0.08	0.21	0.10	0.06	0.34	0.43	0.42	0.42
%P	46.5	51.8	54.2	55.6	52.0	53.2	74.4	60.6	45.1
%O	17.1	22.0	16.8	16.9	24.0	12.4	5.9	12.8	8.0
%A	36.4	26.2	30.0	27.5	24.0	34.4	19.6	26.6	46.9
NO†	70.0	1480.0	15.0	30.0	1580.0	15.0	10.0	10.0	5.0
NO_2†	25.0	320.0	20.0	20.0	380.0	15.0	10.0	10.0	15.0
NO_x†	95.0	1800.0	35.0	50.0	1960.0	30.0	20.0	20.0	20.0

* ppbC

† ppb

and not other combustion sources. The CO concentrations for samples H06, H07, H08, and H09, range from 0.22 to 0.35 ppm. At these levels the contribution of natural background CO (approximately 0.10 ppm) is significant. If this background value is removed from the observed CO concentration and the calculation repeated, better agreement of vehicular percentage is obtained for both factors.

In some areas of Houston, industrial sources of both C_2H_2 and CO may be important. In these cases other vehicular factors such as an unreactive paraffinic or aromatic compound could be utilized. Two such examples are benzene and n-hexane. Kopczynski et al. (8) utilized indicator compounds other than C_2H_2 to determine common sources for several HC components. Although not specifically stated, these indicator compounds served a dual role of accounting for vehicular and non-vehicular sources, such as gasoline spillage and evaporative emissions.

The meteorological conditions on September 11 are described in detail in Appendix B; these conditions are usually associated with rather high inversion layers and good vertical mixing. Consequently, low concentrations of ground level HC were expected. Indeed low levels of total NMHC were observed for all samples, with the exception of the urban sample H01; which contained 1567 ppbC. Total NMHC concentrations at the industrial sites ranged from 346. to 530. ppbC. These concentrations are much lower than those suggested by TACB personnel and only two to three times greater than the background HC levels of 197 ppbC observed at the east gulf coast site (sample H09).

Nitrogen oxide measurements were made for the sample bags, since the storage times of these samples were >12 hrs. These results are reported in Table 2. Previous laboratory storage studies of NO_x-air mixtures have shown reasonable storage of NO_x for up to 24 hr with ~20-30% conversion of NO to NO_2 due to thermal oxidation. When storage times were increased, NO_x levels decreased, a probable result of NO_2 loss to the bag surface. These previous NO_x storage studies suggest the NO_x measurements in the Houston air sample bags are reasonably accurate; however, the inaccurate NO to NO_2 ratios are expected. As a point of interest, the photochemical O_3 potential of the ambient air in Houston was calculated using the standard ozone isopleths

utilized for the EKMA model (10). Assuming that the morning levels of non-methane hydrocarbon and nitrogen oxides were similar to those given in Table 2 i.e., NMHC to range from 350-1500 ppbC and NO_x to range from 20 to 95 ppb, the afternoon ozone maximum was calculated to exceed 80 ppb. Figure 2 represents O_3 levels observed at the TACB CAMS #1 station on September 11, 1973; such levels are lower than the 80-ppb level calculated by the isopleth method. The differences are probably due to differences in meteorological conditions between isopleth model and real atmosphere, and to imperfections of the isopleth method.

Although these HC/NO_x ratios may be somewhat high, they are not extraordinarily different than those found in other cities.

Vehicular hydrocarbons at the non-tunnel sites can be estimated by comparing HC/C_2H_2 or HC/CO ratios from non-tunnel samples to those ratios obtained in tunnel samples (Table 2). These comparisons are valid only if vehicular sources are the only significant source of C_2H_2 CO and if the tunnel auto emissions do not differ significantly from those in the city.

Significant non-vehicular sources of paraffins, olefins, and aromatics were observed at most sampling sites. At some of these locations, vehicular sources can account for only 10-15% of the total NMHC. In contrast, at site H01, representing the urban plume, ~50% of the total HC can be attributed to vehicular sources. These values of vehicular emission at the various sites are in general agreement with those reported in the Westberg et al. Houston study (3). Closely inspecting the individual components of the samples collected at the industrial sites and contrasting their ratios to C_2H_2 with corresponding tunnel sample ratios suggest that the non-vehicular paraffins compounds consist principally of the C_4 to C_6 variety. Similar inspection of the olefin components indicates non-vehicular sources of the C_2 to C_4 compounds. These sample carbon components are consistent with components of petroleum refinery type emissions. Non-vehicular sources of toluene, m-xylene and 1,2,4 tri-methyl benzene are suggested by a similar treatment of the aromatic compounds. Industrial sources of these aromatic compounds are certainly possible; however, it is also possible that these compounds could be halogenated or oxygenated compounds having retention times similar to the identified aromatic compounds.

As alluded to earlier, non-vehicular sources of gasoline spillage and gasoline evaporative emissions contribute significantly to the total NMHC burden. A series of indicator compounds could possibly be utilized to estimate the contribution of these sources, if the general HC composition of the gasoline utilized during this sample period were known. Since this information was not available, these calculations were not performed.

These few samples cannot characterize a typical atmospheric composition for the Houston area, since meterological conditions are expected to cause both HC compositional and concentration variations. However, from these few samples, four conclusions can be made:

1. HC concentrations at these industrial sites do not routinely exceed 1 ppmC and depend greatly on meteorological conditions.
2. A significant percentage of the NMHC at these industrial sites resulted from non-vehicular sources.

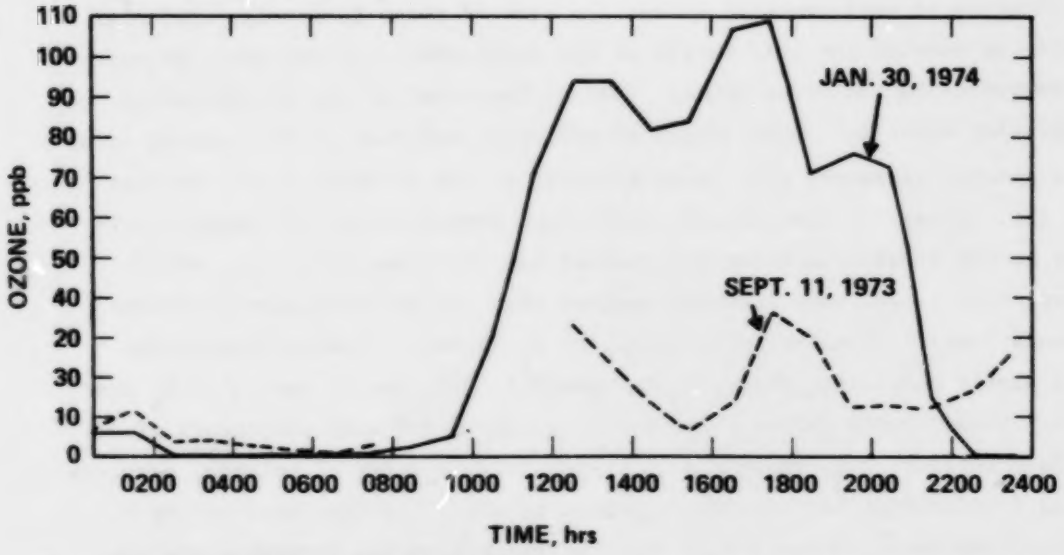

Figure 2. Ozone profiles at the Texas CAMS #1 (1262 Mae Drive) for the days grab samples were collected in the Houston area.

3. The HC/NO_x ratio in the Houston area does not significantly differ from that in other urban areas.

4. Since HC/NO_x ratios are not atypical compared to other urban areas and significant non-vehicular HC sources were observed, significant non-vehicular NO_x sources are suggested.

January 30, 1974

The purpose of the bag sample study conducted on January 30, 1974, was to determine the effect of stable meteorological conditions on HC composition and concentration. Tedlar bags were sent to the TACB for sample collection during stagnant meteorological conditions. Sample site and identification are given in Figure 1 and Table 1. Detailed results of the g.c. analysis of the collected samples are givne in Table A-2.

HC pollutant levels during this study appear approximately an order of magnitude higher than those measured on September 11, 1973. This difference is evident when the NMHC sum or the CO concentrations on the two days are compared. Furthermore, many of the individual hydrocarbons showed corresponding increases, suggesting similar pollution sources on both September 11 and January 30.

A January 30 meteorological analysis revealed a high pressure system centered directly over the Houston area. Since land-based high pressure systems generally occur north of Houston, the NMHC levels observed in these samples are assumed maximum or near maximum for the Houston area. The reported wind direction during sample collection was from WSW to WNW. The wind speed was reported < 2 mph during the entire sample collection period; however, decreased concentrations in samples H16, H17, and H18 suggest a wind speed increase associated with a general breakup of the inversion conditions later in the morning. An Air Stagnation Advisory was issued at 11:00 a.m. by the TACB. A more detailed meteorological analysis is given in Appendix B.

Shown in Table 3 are ratios of sums of paraffins, olefins, and aromatics to both C_2H_2 and CO. No tunnel samples were collected during this study; therefore, in order to estimate vehicular emission contribution, the tunnel ratios determined during the September 11, 1973, study were used. Estimates

of percentage vehicular emissions are also given in Table 3. Applying these runnel ratios to the January 30 data demonstrates that vehicular sources can account for 50-100% of the NMHC observed at these sample sites. This percentage range is considerably higher than percentages measured on September 11 and suggests that during stagnation conditions vehicular sources contribute more significantly to NMHC emissions. This NMHC percentage variation does not represent diminished industrial emissions during stagnant conditions, but it does suggest that ambient HC composition can change under different meteorological conditions. If we assume that the remaining non-vehicular NMHC fraction is of industrial origin, concentrations exceeding 2.00 ppmC can be attributed to these sources. However, spilled and evaporated gasoline sources must also be included in the non-vehicular fraction.

TABLE 3. JANUARY 30, 1974, MEASUREMENTS

	SAMPLE						
Component	H12	H13	H14	H15	H16	H17	H18
ΣP^*	3819.2	2613.9	3945.2	6746.7	1752.7	2112.1	2220.8
ΣO^*	493.6	519.8	781.0	991.4	297.7	372.2	275.9
ΣA^*	802.0	772.5	1176.0	1215.0	799.6	750.8	815.0
$\Sigma P/C_2H_2$	29.9	9.5	24.0	19.4	20.9	23.7	14.6
$\Sigma O/C_2H_2$	3.9	1.9	4.8	2.9	3.5	4.2	1.8
$\Sigma A/C_2H_2$	6.3	2.8	7.2	3.5	9.5	8.4	5.4
$\Sigma P/CO$	0.74	0.35	0.46	0.40	0.43	0.56	0.42
$\Sigma O/CO$	0.10	0.07	0.09	0.06	0.07	0.10	0.05
$\Sigma A/CO$	0.16	0.10	0.14	0.07	0.20	0.20	0.15
%P	74.6	66.9	66.7	75.2	61.7	65.3	67.0
%O	9.7	13.4	13.3	11.2	10.3	11.6	8.3
%A	15.7	19.7	20.0	13.6	28.0	23.1	24.7

* ppbC

Some of the sample sites for this study were identical to those used in the study of September 11, 1973. Samples H14 and H17 were collected at the Pasadena site used for the collection of H03. Likewise, samples H13 and H16 were collected at the San Jacinto site used for the collection of sample H04. In general, the compositional results of the two studies are in agreement. In both studies, large non-vehicular emissions were observed at the Pasadena site, and lower non-vehicular emissions were observed at the San Jacinto site.

Comparison between the Table 3 (January 30) sums of paraffins, olefins, and aromatics ratios to C_2H_2 and CO and the Table 2 (September 11) tunnel ratios shows additional sources of paraffins in all but one Table 3 sample (H13). Additional sources of aromatic compounds and to a lesser extent olefinic compound, are observed in just a few January 30 samples. This is contrary to the industrial site samples of September 11, where significant contribution of both olefinic and aromatic compounds were observed. In both the September 11 and January 30 samples the principal non-vehicular paraffin compounds consisted of the C_4-C_6 components.

These January 30 samples contain extremely high concentrations of methane, ethane, and propane, observed especially in the earlier morning samples (H12, H13, H14, and H15); A natural gas origin possibly the numerous Houston area oil fields is the probable source. Also the abundant use of natural gas, the principal fuel source for area electric power generation, likely gives rise to large fugitive natural gas loss. Since these bags were stored for periods up to 190 hours before analysis, nitrogen oxide measurements were not made.

Shown in Figure 2 are ambient O_3 values at the TACB CAMS Number 1 station for January 30. Ozone was observed for a period of ~ 10 hr to exceed the NAQS standard, while maximum O_3 approached 110 ppb. Although this value is high, it is lower than that expected for the stagnated January 30 conditions. The somewhat lower temperature and decreased sunlight during January were no doubt responsible for reduced O_3 formation.

Four observations can be made from the study of January 30, 1974.

1. Even under the extreme inversion conditions of that day, total NMHC did not exceed 10 ppmC in these areas of Houston.

2. Industrial HC sources were significant but did not dominate the total NMHC emissions.

3. The HC composition of samples collected at identical sites during the September 11, 1973, and January 30, 1974, studies were similar, although the different meteorological inversion conditions were different.

4. Since a high pressure system was centered over the Houston area on January 30, the NMHC levels measured in that day can be considered to be near the maximum levels expected to occur in Houston.

April 2, 1974

Samples collected on April 2, 1974, were included in this report, even though these samples were collected near vinyl chloride and polyvinyl chloride plants to determine ambient levels of vinyl chloride. These sampling sites, shown in Figure 1, were in the general collection site areas for the September 11 and January 30 studies. The HC analysis results are given in Tables 4 and A-3. The total NMHC levels for these samples were comparable to those levels observed in the September 11 study, as shown in a comparison of Table A-1 with Table A-3 results. A general summary of the meteorological conditions on April 2 is given in Appendix B.

TABLE 4. APRIL 2, 1974, MEASUREMENTS

	SAMPLE				
	H21	H22	H23	H24	H25
ΣP^*	469.8	546.9	1105.7	106.4	125.8
ΣO^*	351.2	147.7	112.7	44.1	26.2
ΣA^*	256.1	244.4	327.9	83.1	59.4
$\Sigma P/C_2H_2$	17.0	71.0	197.4	31.3	8.7
$\Sigma O/C_2H_2$	12.7	19.2	20.1	13.0	1.8
$\Sigma A/C_2H_2$	9.3	31.7	58.5	24.4	4.1
$\Sigma P/CO$	0.20	1.09	1.78	0.19	0.34
$\Sigma O/CO$	0.15	0.30	0.18	0.08	0.07
$\Sigma A/CO$	0.11	0.49	0.53	0.15	0.16
%P	43.6	58.2	71.5	45.6	59.5
%O	32.6	15.8	7.3	18.9	12.4
%A	23.6	26.0	21.2	35.5	28.0

* ppbC

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APPENDIX A

DETAILED HYDROCARBON RESULTS

Included in Appendix A are detailed HC species results obtained from air samples collected in the Houston area on September 11, 1973, January 30, 1974, and April 2, 1974. Individual component concentrations for the NMHC are given in parts per billion carbon (ppbC). The concentrations of methane and carbon monoxide in air are in parts per million concentration (ppm).

TABLE A-1. DETAILED HC ANALYSIS (ppbC)* OF AIR SAMPLES COLLECTED IN HOUSTON ON SEPTEMBER 11, 1973

Compound	SAMPLE				
	H01	H02	H03	H04	H05
Ethane	35.1	115.3	24.8	21.7	182.3
Ethylene	174.7	958.0	30.8	24.5	1362.7
Propane	28.0	26.5	22.7	19.0	82.6
Acetylene	41.9	513.0	8.8	20.7	829.7
Isobutane	41.5	102.0	21.4	11.4	259.6
n-Butane	111.3	604.5	38.0	29.2	729.8
Propylene	22.5	405.8	7.3	9.6	512.2
Isobutylene	20.8	233.2	8.4	11.6	412.9
trans-2-Butene	4.1	54.8	4.0	4.0	67.3
cis-2-Butene	2.5	24.0	1.0	0.0	30.0
1,3-Butadiene	4.1	121.1	2.8	4.0	133.2
Isopentane	117.8	995.9	42.1	33.5	1227.0
n-Pentane	58.5	435.2	20.8	20.0	567.6
1-Pentene	4.8	30.9	1.7	1.3	38.4
2 Methyl-1-Butene	7.1	48.4	1.8	1.1	53.8
trans-2-Pentene	9.4	88.3	2.9	2.2	137.5
cis-2-Pentene	11.4	48.9	7.8	1.3	63.5
2 Methyl-2-Butene	7.9	69.1	3.1	1.8	91.9
Acetaldehyde					
Cyclopentane					
Isoprene					
2-Methylpentane	52.3	603.6	21.7	19.8	653.4
3-Methylpentane	21.8	275.7	7.3	8.5	287.9
4 Methyl-2-Pentene	0.0	25.1	0.0	0.0	27.5
n-Hexane	30.4	230.4	14.3	8.5	273.4
1-Hexene	0.0	18.7	0.0	0.0	28.8
Unknown	0.0	41.9	0.0	0.0	73.5
trans-3-Hexene					
2,4 Dimethyl pentane	7.2	132.0	5.0	2.1	153.0
Methylcyclopentane	12.7	296.2	10.1	4.7	286.8
cis-2-Hexene					
Unknown	0.0	34.2	0.0	0.0	25.8
Propionaldehyde					
Acetone					
3,3 Dimethylpentane	8.0	12.4	0.0	0.0	13.0
Cyclohexane		23.2	0.0	0.0	134.3
2 Methylhexane	15.3	174.2	0.0	0.0	211.2
2,3 Dimethylpentane	22.5	99.2	0.0	0.0	191.2
3 Methylhexane	22.9	182.9	0.0	0.0	231.8
1 c 3 Dimecyclopentane	0.0	53.2	0.0	0.0	75.5
2,2,4 Trimethylpentane	32.0	293.6	0.0	0.0	416.3
1 t 3 Dimecyclopentane					
n-Heptane	16.2	138.9	0.0	0.0	100.3

(continued)

TABLE A-1. (Continued)

Compound	Sample H06	H07	H08	H09
Ethane	25.0	13.8	17.0	16.2
Ethylene	10.1	13.9	16.8	6.3
Propane	33.7	18.8	19.9	13.0
Acetylene	4.3	2.0	3.8	1.7
Isobutane	24.8	16.8	40.4	5.8
n-Butane	33.3	52.6	50.7	11.5
Propylene	13.5	3.5	4.2	0.1
Isobutylene	8.4	1.1	14.7	4.5
trans-2-Butene	2.0	1.5	6.8	0.0
cis-2-Butene	2.0	0.0	6.5	0.0
1,3-Butadiene	2.0	0.0	0.0	0.0
Isopentane	14.3	78.2	57.4	9.4
n-Pentane	7.9	76.7	44.1	7.7
1-Pentene	1.2	0.0	3.2	0.0
2 Methyl-1-Butene	1.3	0.0	3.5	0.0
trans-2-Pentene	1.1	1.7	4.2	0.0
cis-2-Pentene	0.0	6.7	4.0	4.0
2 Methyl-2-Butene	1.2	0.0	3.8	0.0
Acetaldehyde				
Cyclopentane				
Isoprene				
2-Methylpentane	4.8	29.3	25.2	4.9
3-Methylpentane	3.8	12.1	12.6	0.0
4 Methyl-2-Pentene	0.0	0.0	0.0	0.0
n-Hexane	6.4	22.2	9.4	0.0
1-Hexene	0.0	0.0	0.0	0.0
Unknown	0.0	2.5	0.0	0.0
trans-3-Hexene				
2,4 Dimethyl pentane	0.0	2.1	8.0	0.0
Methylcyclopentane	0.0	6.0	24.0	0.0
cis-2-Hexene				
Unknown	0.0	0.0	0.0	0.0
Propionaldehyde				
Acetone				
3,3 Dimethylpentane	0.0	0.0	0.0	0.0
Cyclohexane				
2 Methylhexane	0.0	0.0	0.0	0.0
2,3 Dimethylpentane	0.0	0.0	0.0	0.0
3 Methylhexane	0.0	0.0	0.0	0.0
1 c 3 Dimecyclopentane	0.0	0.0	0.0	0.0
2,2,4 Trimethylpentane	0.0	0.0	0.0	0.0
1 t 3 Dimecyclopentane				
n-Heptane	0.0	0.0	0.0	0.0
Methylcyclohexane	0.0	0.0	0.0	0.0

(continued)

TABLE A-1. (Continued)

Compound	SAMPLE HO1	HO2	HO3	HO4	HO5
Methylcyclohexane	16.8	73.5	0.0	0.0	100.3
Toluene	132.0	887.8	35.6	44.2	1014.0
n-Nonane	19.9	69.2	6.4	7.8	74.2
Ethylbenzene	19.8	124.3	6.7	5.3	154.2
p-Xylene	20.0	101.4	5.0	5.3	150.0
m-Xylene	86.1	420.5	13.0	21.0	521.7
o-Xylene	75.1	162.6	8.8	8.4	205.7
Isopropylbenzene	13.5		7.3		
n-Decane	20.4	103.6	10.1	8.7	98.0
n-Propylbenzene	3.8	46.6	4.5	1.3	61.1
p-Ethyltoluene	15.5	213.6	10.9	5.8	268.8
m-Ethyltoluene					
1,3,5 Trimethylbenzene	15.5	66.1	0.0	2.6	77.5
o-Ethyltoluene	5.7	61.0	9.6	1.5	78.5
1,2,4 Trimethylbenzene	182.9	221.6	31.8	6.8	245.5
Unknown	36.6	18.3		10.1	17.5
1,2,3 Trimethylbenzene	0.0	51.2	2.3	0.0	54.2
n-Butylbenzene + P-Diethylbenzene	0.0	60.0	0.0	0.0	51.2
m-Diethylbenzene	0.0	108.0	0.0	0.0	97.0
Unknown	0.0	27.6	0.0	0.0	27.4
Sum of Other Unknowns on MBMA Column					
Sum of Other Unknowns on DBM Column					
Methane *	2.01	2.05	1.77	1.75	2.83
Carbon monoxide *	2.04	34.0	0.65	1.05	46.8

* Methane and CO concentrations are expressed as parts per million (PPM)

TABLE A-1. (continued)

Compound	SAMPLE HO6	HO7	HO8	HO9
Toluene	39.5	14.2	35.8	39.3
n-Nonane	4.7	1.4	5.7	13.8
Ethylbenzene	2.5	3.1	6.6	3.9
p-Xylene	4.0	3.2	6.0	4.6
m-Xylene	10.6	9.4	8.1	7.5
Unknown	8.2	7.4	7.9	8.9
o-Xylene				
Isopropylbenzene	4.7	0.0	7.6	0.0
n-Decane	10.4	11.9	6.9	7.0
n-Propylbenzene	0.0	0.0	2.8	0.0
p-Ethyltoluene	1.0	1.9	11.5	6.0
m-Ethyltoluene				
1,3,5 Trimethylbenzene	2.2	0.1	5.4	3.8
o-Ethyltoluene	2.2	0.1	4.7	3.9
1,2,4 Trimethylbenzene	7.8	7.1	45.6	11.0
Unknown	15.1	10.9	0.0	0.0
1,2,3 Trimethylbenzene	0.0	47.1	0.0	0.0
n-Butylbenzene + p-Diethylbenzene	36.3	0.0	0.0	0.0
m-Diethylbenzene	0.0	0.0	0.0	0.0
Unknown	0.0	0.0	0.0	0.0
Sum of Other Unknowns on MBMA Column				
Sum of Other Unknowns on DBM Column				
Methane *	1.76	1.62	1.75	1.53
Carbon monoxide *	0.35	0.22	0.34	0.22

* The concentrations of these compounds are parts per million (PPM)

TABLE A-2. DETAILED HC ANALYSIS (ppbC)* OF AIR SAMPLES COLLECTED IN HOUSTON ON JANUARY 30, 1974

Compound	Sample H12	H13	H14	H15	H16
Ethane	283.7	197.9	280.8	751.8	188.1
Ethylene†	143.0	201.9	262.8	331.9	331.9
Propane	247.7	160.5	285.6	592.4	214.7
Acetylene	127.6	277.8	164.1	347.8	83.9
Isobutane	158.7	128.8	171.9	305.7	80.4
n-Butane	827.2	624.8	707.4	1604.1	233.1
Propylene	88.3	81.1	109.3	153.9	37.2
Isobutylene	47.1	66.5	65.0	107.0	29.8
trans-2-Butene	18.8	16.9	24.7	32.2	7.5
cis-2-Butene	18.0	14.4	18.0	32.0	4.7
1,3-Butadiene	7.1	20.1	49.3	23.0	11.8
Isopentane	641.5	416.4	675.4	1076.0	192.8
n-Pentane	277.4	197.2	281.1	453.2	103.0
1-Pentene	14.5	9.5	20.8	28.9	7.0
2 Methyl-1-Butene	24.3	16.1	36.3	47.6	8.7
trans-2-Pentene	45.3	32.5	59.5	80.0	23.3
cis-2-Pentene	17.1	9.4	23.1	29.6	7.0
2 Methyl-2-Butene	39.8	29.8	52.6	67.8	8.5
Acetaldehyde					
Cyclopentane	53.1	38.8	58.1	81.5	19.9
Isoprene					
2-Methylpentane	169.1	114.0	192.8	267.7	76.7
3-Methylpentane	112.2	75.8	136.2	173.4	47.3
4 Methyl-2-Pentene	13.1	7.0	21.3	11.2	2.3
n-Hexane	101.2	74.3	153.3	176.8	81.3
1-Hexene	5.5	7.7	24.2	27.6	0.0
Unknown	13.2	7.5	22.0	24.2	6.5
trans-3-Hexene	11.7	7.0	14.1	18.7	0.0
2,4 Dimethyl pentane	36.7	21.6	49.3	55.3	25.0
Methylcyclopentane	79.6	56.3	114.7	142.3	41.0
cis-2-Hexene	18.4	9.1	24.9	24.6	0.0
Unknown	19.7	11,7	7.9	16.1	0,0
Propionaldehyde					
Acetone					
3,3 Dimethylpentane	10.7	5.1	3.7	8.9	0.0
Cyclohexane	19.6	18.9	37.1	42.7	15.7
2 Methylhexane	45.6	43.6	68.1	76.2	28.1
2,3 Dimethylpentane	48.4	44.6	72.1	74.4	26.3
3 Methylhexane	71.0	56.6	85.0	119.3	41.0
1 c 3 Dimecyclopentane	26.6	14.0	20.7	28.4	15.9
2,2,4 Trimethylpentane	118.9	72.7	146.8	157.9	51.9
1 t 3 Dimecyclopentane	56.2	29.9	34.9	66.4	41.3
n-Heptane	71.1	34.9	81.3	60.4	23.8
Methylcyclohexane	260.0	131.8	90.0	229.8	154.0

(continued)

TABLE A-2. (Continued)

Compound	Sample H17	H18
Ethane †	142.8	73.6
Ethylene †	149.9	124.3
Propane	171.2	45.7
Acetylene	89.1	151.8
Isobutane	142.9	58.6
n-Butane	418.9	236.3
Propylene	45.2	36.4
Isobutylene	42.7	30.7
trans-2-Butene	14.8	6.7
cis-2-Butene	13.0	5.5
1,3-Butadiene	50.6	7.2
Isopentane	375.0	268.8
n-Pentane	151.4	112.8
1-Pentene	8.0	5.9
2 Methyl-1-Butene	12.0	9.4
trans-2-Pentene	37.8	21.7
cis-2-Pentene	10.0	6.0
2 Methyl-2-Butene	11.7	8.1
Acetaldehyde		
Cyclopentane	28.1	26.8
Isoprene		
2-Methylpentane	97.5	87.8
3-Methylpentane	58.7	59.6
4 Methyl-2-Pentene	0.0	4.4
n-Hexane	86.9	56.5
1-Hexene	0.0	4.2
Unknown	5.7	8.7
trans-3-Hexene	3.2	5.6
2,4 Dimethyl pentane	15.2	22.0
Methylcyclopentane	55.5	45.2
cis-2-Hexene	0.0	0.0
Unknown	0.0	0.0
Propionaldehyde		
Acetone		
3,3 Dimethylpentane	0.0	0.0
Cyclohexane	15.6	10.2
2 Methylhexane	26.1	38.9
2,3 Dimethylpentane	20.2	40.9
3 Methylhexane	35.2	58.4
1 c 3 Dimecyclopentane	12.3	17.4
2,2,4 Trimethylpentane	39.1	76.1
1 t 3 Dimecyclopentane	25.1	47.9
n-Heptane	31.1	32.9
Methylcyclohexane	81.3	196.8

(continued)

TABLE A-2. (Continued)

Compound	Sample H12	H13	H14	H15	H16
Toluene	230.8	219.1	415.0	371.6	187.4
n-Nonane	22.1	18.1	49.2	47.2	11.2
Ethylbenzene	41.9	47.0	54.6	59.3	39.4
p-Xylene	32.7	28.4	50.0	44.6	29.0
m-Xylene	118.4	124.6	155.8	167.1	101.1
o-Xylene	57.8	53.2	74.3	79.6	50.8
Isopropylbenzene			11.0	23.5	44.2
n-Decane	13.9	6.3	56.3	46.4	33.8
n-Propylbenzene	15.8	13.1	18.8	21.5	6.5
p-Ethyltoluene	45.2	49.2	68.4	85.7	34.4
m-Ethyltoluene					
1,3,5 Trimethylbenzene	51.6	46.6	45.2	68.9	50.8
o -Ethyltoluene	10.0	10.0	19.3	30.0	16.0
1,2,4 Trimethylbenzene	60.6	47.0	67.8	80.7	39.5
Unknown					
1,2,3 Trimethylbenzene	94.8	79.4	114.5	87.7	124.1
n-Butylbenzene + p -Diethylbenzene m-Diethylbenzene	15.4	11.7	17.8	14.8	9.4
Unknown	26.8	43.0	63.5	80.0	67.0
Sum of Other Unknowns on MBMA Column					
Sum of Other Unknowns on DBM Column					
Methane *	7.15	4.64	6.46	12.1	4.01
Carbon monoxide *	5.13	7.63	8.54	16.7	4.04

* Methane and CO concentrations are expressed in parts per million (ppm)

† Ethylene peaks are contaminated by the effluent from the Ethylene-Ozone Chemiluminescent Instrument

TABLE A-2. (Continued)

Compound	Sample H17	H18
Toluene	223.3	196.5
n-Nonane	14.9	11.1
Ethylbenzene	35.3	31.0
p-Xylene	27.8	24.5
m-Xylene	88.8	73.8
o-Xylene	42.0	45.6
Isopropylbenzene	28.6	45.7
n-Decane	40.8	33.6
n-Propylbenzene	5.9	10.0
p-Ethyltoluene	21.4	34.7
m-Ethyltoluene		
1,3,5 Trimethylbenzene	39.3	64.8
o-Ethyltoluene	10.0	10.0
1,2,4 Trimethylbenzene	28.5	41.8
Unknown		
1,2,3 Trimethylbenzene	152.8	151.6
n-Butylbenzene +	11.1	17.0
p-Diethylbenzene		
m-Diethylbenzene		
Unknown	36.0	68.0
Sum of Other Unknowns on MBMA Column		
Sum of Other Unknowns on DBM Column		
Methane *	3.50	2.43
Carbon monoxide *	3.76	5.34

† Ethylene peaks are contaminated by the effluent from the Ethylene-Ozone Chemiluminescent Instrument.

* Methane and CO concentrations are expressed in parts per million (ppm).

TABLE A-3. DETAILED HYDROCARBON ANALYSES (ppbC)* OF AIR SAMPLES COLLECTED IN HOUSTON ON APRIL 2, 1974

Compound	SAMPLE H21	H22	H23	H24	H25
Ethane		41.8	32.7	22.6	17.4
Ethylene	274.7	78.2	38.0	32.7	10.6
Propane	105.8	63.9	71.6	26.3	21.5
Acetylene	27.6	7.7	5.6	3.4	14.4
Isobutane	35.5	39.7	98.8	8.4	7.7
n-Butane	53.5	71.1	147.7	20.7	31.8
Propylene	17.5	27.9	21.2	3.1	4.2
Isobutylene	21.2	21.0	8.7	1.5	1.8
trans-2-Butene	4.9	1.8	3.2	1.3	0.9
cis-2-Butene	3.1	1.1	2.6	0.0	0.2
1,3-Butadiene	7.5	1.4	1.6	0.0	
Isopentane	80.9	77.4	347.8	5.2	20.1
n-Pentane	44.7	42.8	133.9	9.7	10.0
1-Pentene	1.6	1.3	3.0	0.5	0.5
2 Methyl-1-Butene	2.0	2.1	3.7	0.0	0.5
trans-2-Pentene	11.8	9.6	20.9	4.5	5.2
cis-2-Pentene	3.1	1.7	4.7	0.5	2.1
2 Methyl-2-Butene	3.9	1.6	4.1	0.0	0.0
Acetaldehyde					
Cyclopentane					
Isoprene	34.9	36.5	74.3	5.2	7.5
2-Methylpentane					
3-Methylpentane	14.7	24.9	30.3	5.1	3.1
4 Methyl-2-Pentene	0.0	0.0	1.0	0.0	0.0
n-Hexane	19.5	27.9	29.3	3.1	3.0
1-Hexene	0.0	0.0	0.0	0.0	0.0
Unknown					
trans-3-Hexene					
2,4 Dimethyl pentane	3.2	1.1	6.2	0.0	0.0
Methylcyclopentane	13.2	12.4	18.5	0.0	0.0
cis-2-Hexene	0.0	0.0	0.0	0.0	0.0
Unknown					
Propionaldehyde					
Acetone					
3,3 Dimethylpentane	0.0	0.0	0.0	0.0	0.0
Cyclohexane	0.0	0.0	0.0	0.0	0.0
2 Methylhexane	9.5	20.5	11.1	0.0	0.0
2,3 Dimethylpentane	6.1	7.8	10.3	0.0	0.0
3 Methylhexane	2.3	3.5	7.0	0.0	0.0
1 c 3 Dimecyclopentane	5.8	10.2	12.5	0.0	0.0
2,2,4 Trimethylpentane	6.1	14.7	28.2	0.0	0.0
1 t 3 Dimecyclopentane					
n-Heptane	6.7	13.3	18.7	0.0	0.0
Methylcyclohexane	4.5	15.8	15.0	0.0	0.0

(continued)

TABLE A-3. (Continued)

Compound	SAMPLE H21	H22	H23	H24	H25
Toluene	48.2	90.5	62.4	22.2	17.0
n-Nonane	2.9	6.6	3.7	0.7	0.6
Ethylbenzene	24.5	13.0	5.7	5.2	3.9
p-Xylene	14.9	28.2	5.9	3.3	2.9
m-Xylene	64.6	36.7	28.4	11.9	10.3
o-Xylene	20.3	14.6	46.5	3.6	3.4
Isopropylbenzene + Styrene	35.5	28.5	20.3	26.8	15.5
n-Decane	19.0	11.2	6.5	4.6	3.1
n-Propylbenzene	9.4	2.7	1.2	0.9	0.2
p-Ethyltoluene m-Ethyltoluene	20.4	10.6	4.6	1.6	2.3
1,3,5 Trimethylbenzene	6.8	4.3	3.0	2.4	2.0
o-Ethyltoluene	2.6	1.0	0.5	0.2	1.4
1,2,4 Trimethylbenzene	5.3	11.6	138.5	3.7	4.0
Unknown	4.1	4.0	9.0	3.6	2.5
1,2,3 Trimethylbenzene	0.6	11.1	10.2	17.1	4.1
n-Butylbenzene + p-Diethylbenzene m-Diethylbenzene	6.4	5.9	5.5	2.8	2.3
Unknown					
Sum of Other Unknowns on MBMA Column					
Sum of Other Unknowns on DBM Column					
Methane *	2.31	2.05	1.96	1.91	1.91
Carbon monoxide	1.04	1.50	0.62	0.57	0.37

* The concentration of these compounds are parts per million (ppm).

† Ethylene peaks are contaminated by the effluent from the Ethylene-Ozone Chemiluminescent Instrument.

APPENDIX B

METEOROLOGICAL EVALUATION OF THE GENERAL AREA

INTRODUCTION

Meteorological parameters affecting the potential for air pollution episodes in Houston, Texas, were examined for the dates September 11, 1973, January 30, 1974, and April 2, 1974. These parameters include temperature, moisture, and wind structure. Synoptic weather patterns were analyzed. Stagnating high pressure systems were identified and tracks of the systems were developed. Mixing depths and inversion layers were identified for each day. Ventilation factors were calculated, and estimates of residence times were made.

RESULTS AND DISCUSSION

September 11, 1973

Synoptic Description — A low pressure cell formed off the Gulf coast of Texas. The cell moved inland as the day progressed. Skies over Houston were overcast the entire day, and thunderstorms developed by midday. Temperatures remained steady throughout the day (range 25°-27°C). Winds remained from a north to northeast direction with speeds averaging 10-15 mph, except in the thunderstorm.

Mixing Depth — The mixing depth is defined as the distance from the ground to the bottom of the first inversion. For this case the mixing depth is very large (2000 m) and the atmosphere is considered unstable (encourages vertical mixing). This situation indicates a good spread of pollutants vertically. Temperature profiles are found in Figure B-1 for the periods of early morning, noon, and early evening.

Ventilation Factor — The ventilation factor is defined as the product of the mixing depth and the average wind between the ground and the top of the mixed layer. The average wind makes up the horizontal transport of air parcels.

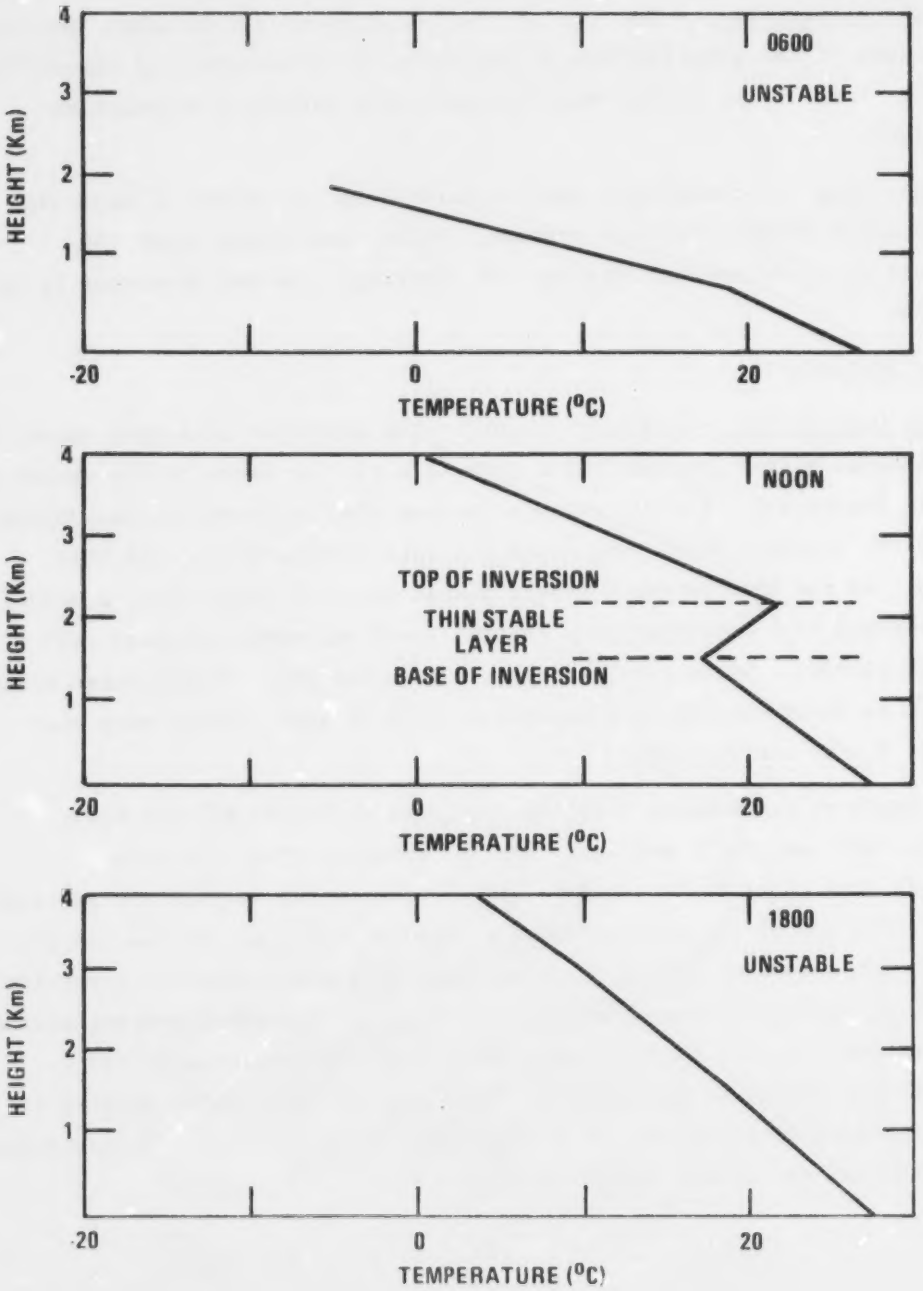

Figure B-1. Vertical temperature profiles, for Houston, Texas, September 11, 1973.

For September 11 the average wind from the surface to 2000 m was 12.5 m/s (25 mph), which gives a ventilation factor of 25,000 m^2/s. For cases of high potential for pollution episodes the ventilation factor can range from near zero (with a surface based inversion) to 6,000 m^2/s. A value of 25,000 m^2/s suggests a small potential for a pollution episode.

Role of Precipitation -- The role of precipitation should be taken into account (1) because of the likely effect of cleansing and (2) because of the difficulty in calculating mixing depths that fluctuate with varying precipitation conditions.

Residence Time --The residence time is defined as the number of days air parcels spend in high pressure systems. Since Houston was under the influence of a low pressure system, the residence time for September 11 is very low.

January 30, 1974

Synoptic Description -- Houston was under the influence of a very large, cold, high pressure system located in the Ohio Valley. The track of the system is shown in Figure B-2. The system made its way from southern Canada, dipped east of the Rockies, moved over Texas and into the Mississipi and Ohio Valleys. As the high pressure system showed signs of stagnation, a secondary high pressure cell developed over central Texas and moved eastward into northern Florida. Skies remained clear the entire day. Temperatures ranged from 9°C in early morning to a maximum of 22°C at noon. Winds were very light (< 3 m/s) and variable.

Mixing Depth -- Temperature profiles are found in Figure B-3 for early morning, noon, and early evening. For the early morning, the mixing depth was very close to the surface (10 m), indicating very little vertical mixing. The top of the inversion was located at ~ 100 m. As the day progressed, the noon time mixing depth was 65 m with the top of the inversion at ~ 900 m, indicating increased vertical mixing. The early evening mixing depth reached its peak at 850 m with the top of the inversion at 900 m. Good vertical mixing is indicated for this time period. Since Houston is in a stagnating anticyclone, the mixing depth at sunset will quickly decrease to height similar to that of the early morning.

Ventilation Factor -- Since the mixing depth and average horizontal wind speed are very low most of the day, a small ventilation factor is determined. This small value indicates a large potential for a pollution episode. Table B-1 shows the values of the ventilation factors for the three time periods examined.

TABLE B-1. HOUSTON, TEXAS, VENTILATION FACTORS FOR JANUARY 30, 1974

Time	Height (m)	Wind Speed (m/s)	Height X Wind Speed (m^2/s)
0600	10	1.0	10.0
1200	65	1.0	65.0
1800	850	2.0	1700.0

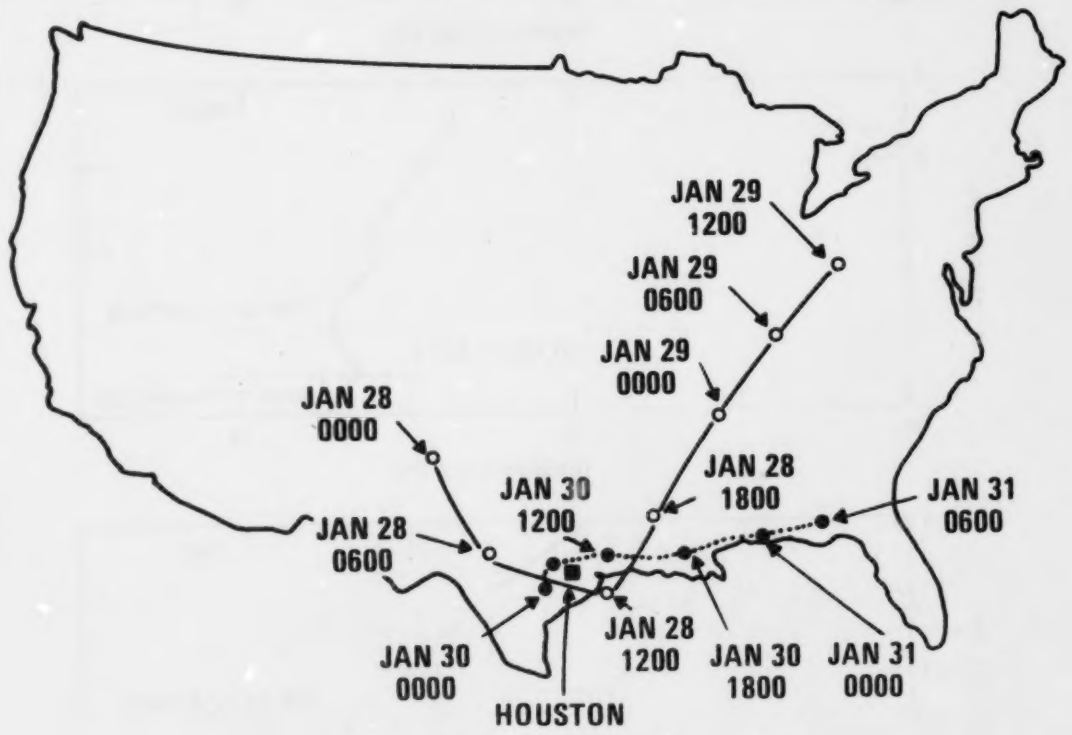

Figure B-2. Tracks of high pressure centers, for the period of Jan. 28 - 31, 1974.

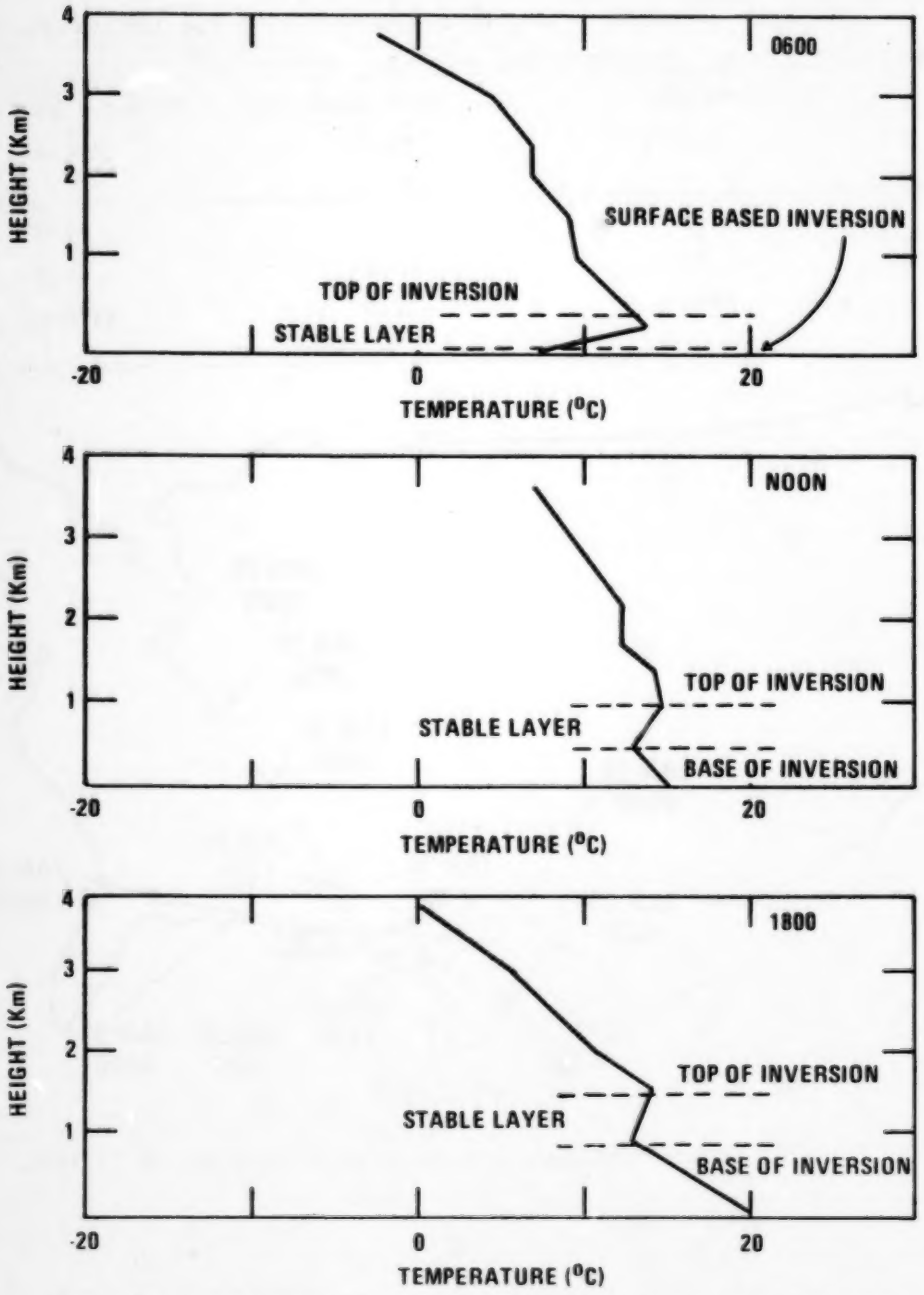

Figure B-3. Vertical temperature profile for Houston, Texas, January 30, 1974.

Residence Time -- Houston was under the influence of a stagnating high pressure system so that an estimate of 3 days for residence time would not be unreasonable.

April 2, 1974

On April 2, 1974, Houston was under the influence of a slowly moving, low pressure cell. A cold front had developed along the cell and moved into Houston by midday. Heavy showers preceded the front as the cloud layer thickened. Winds were strong, from the southwest (10 m/s); after the passage of the front, they shifted to the northwest and remained fairly strong (8 m/s). Temperatures ranged from 26°C in midday to 17°C by early evening.

Temperature profiles were taken for early morning and early evening. Both profiles showed the cold front. No early morning surface-based inversion was found. For the early morning, the base of the inversion was at 800 m with the top of the inversion at 1100 m. The mixing depth was 800 m. The average wind speed in the mixing layer was 5 m/s and the ventilation factor 4000 m^2s (800 m X 5 m/s).

The evening temperature profile showed the same 800 m inversion base, but a wind speed increase (~ 7.5 m/s) in the layer was noted. The ventilation factor then was 6000 m^2/s. This factor represents the upper limit for pollution potential, but no pollution problem existed. This is perhaps due to the role precipitation plays in cleansing the atmosphere of its pollutants.